Capturing and Displaying Uncertainty in the Common Tactical/Environmental Picture:

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LONG-TERM GOALS

The long-term goal is to develop methods to characterize and display the uncertainty in target state estimates that result from uncertainty in environmental estimates.

OBJECTIVES

The objectives of this project for FY03 were (1) were to work with APL/UW and ARL/UT to develop methods for modeling and computing the distribution of the uncertainty in Signal Excess (SE) prediction for multistatic active detection of submarines resulting from uncertainty in environmental predictions, and (2) to develop methods for accounting for this uncertainty in a Likelihood Ratio Tracker (LRT).

APPROACH

We characterized and quantified the uncertainty in the environmental predictions for the components of the sonar equation for multistatic active detection, and incorporated this characterization into a Bayesian track-before-detect system called, the Likelihood Ratio Tracker (LRT).

For multistatic active detection, the predicted mean SE (in dB) for a single sensor in the multistatic system is given by Urick (reference [1]) as

$$\overline{SE} = SL - TL_1 - TL_2 + TS - RL - DT \tag{1}$$

Where SL is source level, TL_1 and TL_2 are transmission loss to the target and from the target to the receiver, TS is target strength, RL is reverberation, and DT is detection threshold. We assume that we are in a reverberation limited case. Urick observes that about this mean $\overline{SE}$ there are short term fluctuations that that are approximately Gaussian in dB. Typically, the fluctuations have mean 0 and standard deviation of $s =$ 8 or 9 dB. Let x be a normal Gaussian random variable with mean 0 and

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standard deviation s. In Urick's model, detection occurs when $\overline{SE} + x > 0$. The variation represented by x is predictable only in a statistical sense and is already accounted for in many tactical decision aids used by the Navy.

The uncertainty that we are primarily concerned with comes from the possibility that we have misestimated the mean of any of the components of the SE equation (1). This produces an uncertainty in $\overline{SE}$, the mean SE. This mis-estimation can be caused by a using a poor estimate of the sound speed profile, bottom type, or any environmental input required for computing $\overline{SE}$. We represent the resulting uncertainty in $\overline{SE}$ by a probability distribution on the prediction error for $\overline{SE}$. To account for this uncertainty, we extended the state space of LRT to include signal excess prediction error as a component of tracker state. The initial distribution on prediction error is computed from the uncertainty distributions on each of the components in (1).

WORK COMPLETED

The IASW version of LRT was modified to include non kinematic state variables such as signal excess prediction error. Using environmental predications and uncertainties representative of an area in the East China Sea, APL/UW and ARL/UT provided estimates of the distribution of prediction error in each component of the sonar equation (1). Metron combined these into an overall distribution on mean SE prediction error that is function of target state. Metron developed a simulator to provide detection and false alarm responses for a simulated target for an example involving a buoy field similar to EER. LRT was run on examples using this simulated data. As sensor responses were obtained, LRT produced joint estimates of target kinematic state and $\overline{SE}$ prediction error. In the cases examined, LRT produced good estimates of target kinematic state and signal excess prediction error in the presence of large numbers of false detections. In addition, LRT was able to track multiple targets, each having a different signal excess prediction error.

Figure 1 shows the output from LRT run on simulated data. This is a multistatic active situation. The buoy locations are indicated by white circles in the lower part of the figure on the left-hand side. As in EER, each buoy consists of a pair, a receiver and source. A source was pinged every four minutes. False alarms were generated through a spatial Poisson process with an average of 10 false alarms received at each buoy for each ping. The responses at the buoys were combined into a measurement likelihood ratio surface and integrated over time to produce the cumulative log-likelihood ratio surface shown on the left-hand side of the figure. Near the top of this figure, we can see a high likelihood (red) area where the target is located. The target's position is indicated by a white circle. The right-hand side of the figure shows the posterior marginal distribution on mean SE prediction error. The initial distribution on this error was uniform over -30 to 30 dB, but the posterior marginal is highly peaked near -20 to -25 dB, which is the correct value.

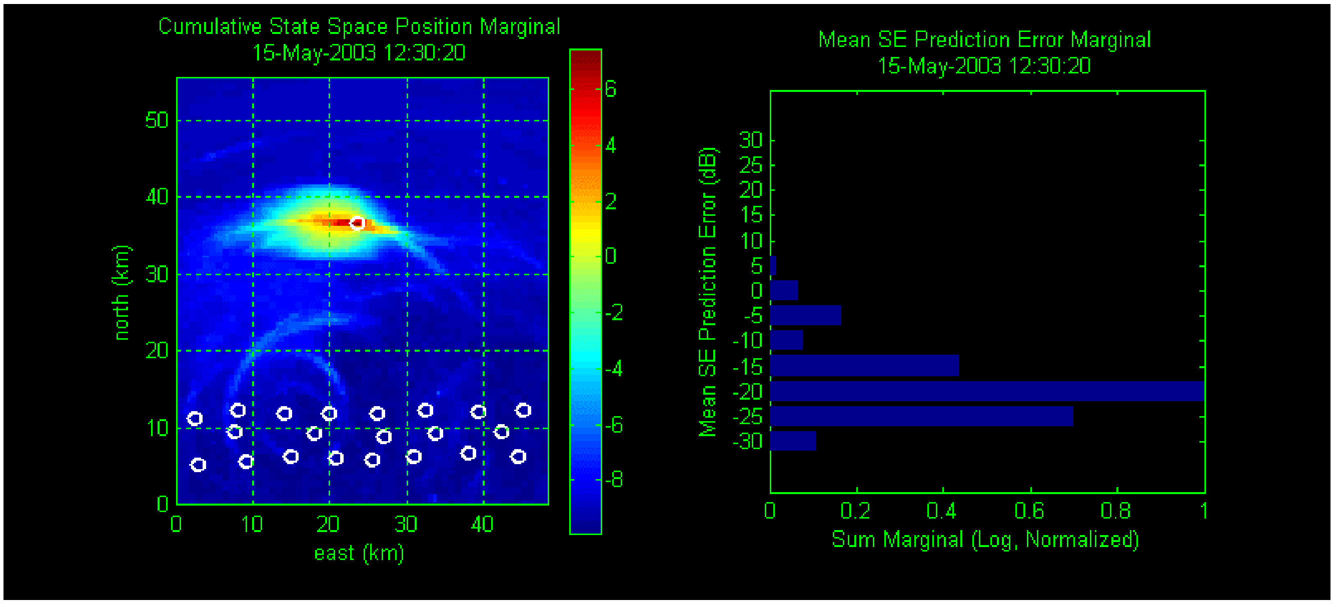

***Figure 1**. Cumulative Likelihood Ratio Surface and Marginal Distribution on SE Prediction Error*

RESULTS

We demonstrated the ability to account for mean SE prediction uncertainty in a track before detect system for multistatic active sonar. The approach has worked well on limited simulation data.

IMPACT/APPLICATIONS

In the past it has been difficult to incorporate sensor performance predictions into trackers because of the uncertainty in these predictions. Sensor performance predictions are particularly useful in providing range information for sonar systems, both passive and active. If an incorrect performance prediction is used, then misleading state (e.g., range) estimates can be produced by a tracker. Accounting for the signal excess prediction uncertainty by incorporating SE prediction error as a state in the tracker state space promises to make trackers more robust to performance prediction error. This will allow trackers to use performance predictions to produce better tracker solutions with out producing misleading results when the predictions are uncertain.

RELATED PROJECTS

The version of LRT developed for this work will used as a basis for Metron's work in ONR's Naval Underwater Warfare Technology project.

REFERENCES

[1] Urick, Robert J. *Principles of Underwater Sound*, 3rd Ed, McGraw-Hill, 1983.